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PLASTICS FROM BAGASSE AND OTHER AGRICULTURAL RESIDUES 1/

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The experimental development of agricultural residues, particularly bagasse, for the production of low-cost molding compounds has received increasing attention in recent years. The United States Department of Agriculture (7) estimated the average annual production, on the dry basis, of straws, corncobs, hulls, corn stover, bagasse and other residues for the period 1931-1935 at more than 173,000,000 tons, of which more than 84,000,000 tons was considered to be available for industrial use. These figures do not include nutshells, fruit pits, weeds and other uncultivated vegetation, or wood wastes, which have chemical and physical characteristics and properties similar to those of the materials cited above. The data for the production of the individual materials and the proximate analyses of some are given in table 1.

The industrial utilization of even a relatively small portion of these agricultural residues would have far-reaching effects on the agricultural and national economy of the United States, because it would result in a larger cash income to the farmer, would increase the degree of national self-sufficiency with regard to a number of strategic raw materials, and would conserve some of our irreplaceable natural resources, such as forests, coal and petroleum.

To make the utilization of these agricultural residues attractive as raw material sources to industry it is necessary to provide their continuous adequate supply to the manufacturing plant at a relatively low cost. The mechanical and economic problems of harvesting, collection, transportation, storage and preservation will have to be better solved before substantial tonnages can be moved into industrial channels. Sugar cane bagasse is in a favored position in that the cost of initial collection and defibering has already been absorbed in the manufacture of sugar. Costs of baling, storing and transportation after receipt from the sugar mill must be borne by the using industry.

A considerable amount of bagasse has been used in the production of structural and insulating board in the last twenty years. However, the total consumption for this purpose in the United States and its insular possessions probably does not exceed 250,000 tons annually. A small amount of the bagasse is used for livestock bedding, poultry litter, stock feed, and for other purposes. The major portion is burned for fuel at the sugar factories.

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The rapid growth of the plastics industry and active interest in the utilization of lignin (one of the principal plant constituents) opens up the possibility of using the lignin-containing agricultural residues for the production of low-cost plastics. Numerous methods for the treatment of these residues and of other lignin-containing materials (2, 3, 6) have been suggested. In 1933 the United States Forest Products Laboratory at Madison, Wisconsin proposed methods for producing plastic molding compounds from sawdust and from some of the agricultural residues (8, 9). These methods consist essentially of hydrolyzing or digesting the raw material at elevated temperatures and pressures with dilute acid or with aniline, and mixing the hydrolyzed residue with suitable plasticizers. These procedures appeared promising for application to the annual crop residues and were chosen for the preliminary studies on bagasse carried out in the Agricultural Byproducts Laboratory of the United States Department of Agriculture at Ames, Iowa. These studies dealt with the effects of such variables as temperature, pressure, period of hydrolysis (digestion), type and amount of plasticizers, etc., and resulted in a number of modifications of the methods (4, 5).

Acid Digestion.

A satisfactory molding composition was obtained from bagasse digested for 30 minutes with one percent sulfuric acid at a pressure of 135 pounds per square inch. After filtering, washing, drying and grinding, the powder was mixed with 8 percent each of aniline and furfural. Specimens molded at about 325° F. under a pressure of 3500 pounds per square inch had a fairly high flexural strength or modulus of rupture (approximately 7000 pounds per square inch), 2.7 percent moisture absorption (fairly low for a 48-hour immersion), a scleroscope hardness of 85, and a specific gravity of 1.42. Some of the physical properties of the molded material are indicated in table 2. The molded products are dense, black, opaque, lustrous and readily machined with high-speed cutting tools or carborundum wheels. Being uniform in physical structure the molded products may be ground, sanded and polished throughout their entire body.

Alkaline Furfural Digestion.

Preliminary tests at this laboratory of molding compounds prepared by digesting bagasse in an alkaline furfural solution and precipitating the dissolved lignin complex by acidification, gave indications that this method of digesting with a combination of plasticizing and pulping agents merits further consideration. Although moisture absorption of specimens molded from compositions to which no additional plasticizing agents had been added was relatively high, the flexural strength approached 7000 pounds per square inch, as indicated in table 2. Additional studies on this method are being conducted.

Aniline Digestion.

Early tests with the aniline digestion method gave specimens exhibiting flexural strengths as high as 9000 pounds per square inch. Extending this investigation molding compositions were prepared from a series of 24 digestions in which the effects of the various factors outlined above were studied. The aniline-digested residues were washed, dried, ground, and mixed with plasticizing agents such as furfural alone, furfural and aniline, or furfural and phenol. Data showing the maximum, minimum and average strength characteristics and other physical properties of 60 specimens molded from powders prepared under varying conditions are given in table 2.

The flexural strength of three commercial phenol-formaldehyde molding compounds was determined for comparison with those obtained with the bagasse molding powders. These phenol-formaldehyde type plastics also exhibited flexural strengths of approximately 7000 pounds per square inch (table 3).

The experiments with aniline digestion indicated that some of the variables in the preparation of the molding powders have definite effects upon the physical properties of the molded product. A low water-bagasse ratio in the digestion charge is necessary for maximum plastic flow and maximum moisture resistance of the finished plastic, and a high ratio is desirable for maximum strength. The optimum amount of aniline for digestion is 20 to 25 percent of the weigth of dry bagasse. Lower digestion pressures tend to give good strength characteristics while higher pressures improve the plastic flow and moisture resistance. While a shorter digestion period at higher pressure increases the strength of the plastic, a longer cooking time at lower pressure is more desirable. A relatively large proportion of fines in the powder apparently enhances the strength of the resulting product, provided the original fiber length is not reduced drastically. Plasticizing of the digested material before grinding tends to increase the strength of the molded product.

Based on these findings, conditions were selected which would be expected to produce a molding compound of a reasonably high degree of flow and good strength characteristics. A molding powder prepared from bagasse under the chosen conditions yielded molded specimens which gave results in line with expectations. This indicates that the molding qualities and physical properties of bagasse powders can be varied to meet definite requirements within reasonable limits (5).

Aniline-bagasse molding powder, although considered thermosetting, exhibits some thermoplastic characteristics. When molded specimens were fused with additional powder at the usual temperature and pressure, it was found to be practically impossible to determine the line of demarcation where fusion had taken place. Molded specimens ground to a fine powder have been remolded under the original conditions of temperature and pressure. Bagasse plastics with metal inserts have been molded successfully in this laboratory, indicating excellent adhesion of the metal to the plastic. Veneers (woods, plastics, metals, etc.) may be applied either at the time of initial molding or as a subsequent operation: Although the molding powders described above always give a lustrous black product, it is possible to incorporate suitable pigments to produce colored and mottled objects. The plastic compositions prepared from the aniline-hydrolyzed bagasse exhibited, in general, greater plastic flow, flexural strength, and resistance to moisture absorption than products prepared by the acid-hydrolysis and alkaline-furfural methods. A pilot-plant for the production of molding powders from bagasse, based on procedures developed at this laboratory, has been erected at a sugar mill in Louisiana. This experimental plant has a capacity of about 200 pounds of powder per day.

These agricultural molding compounds have aroused a great deal of interest in the automotive and rubber industries, resulting in cooperative experimental work between this laboratory and the research organizations of some of the large automobile and rubber manufacturers. During this cooperative work it was found that the aniline-bagasse molding powders can be compounded with some synthetic rubber materials, as well as with natural rubber. This led to a number of possible applications. Automobile steering wheels molded from a mixture of aniline-bagasse powder and synthetic rubber have passed all laboratory and service tests. A gasket material prepared from a similar mixture apparently has excellent oil-resistance and, if not subjected to heat, is superior to the usual gasket type of packing due to its high recovery or resiliency. Aniline-bagasse powder may also be substituted for part of the shellac or similar products in the preparation of the hard, dense, lustrous materials used for fender guards. The automobile industry has also shown considerable interest in the use of molding powders from agricultural residues for production of buttons, knobs, dashboards, panels and other automobile parts and garnishing.

The molded plastic may find use as electrical insulation material in the manufacture of radio and other electrical equipment. Tests on specimens prepared during early studies have shown that some agricultural residue plastics have an electrical resistance, at 30 percent relative humidity, of approximately 5 x 10^{11} ohms per square centimeter, a value comparable with that of phenol-formaldehyde and phenol-furfural plastics.

The strength characteristics, workability and relatively high moisture resistance of products molded from agricultural residues may be of interest to the building and furniture industries. If products such as floor and ceiling moldings, tiles, table and desk tops, window frames, furniture and numerous other articles could be made at low cost and with desirable properties not attained by materials used at present, it might be possible to move substantial quantities of residues into these industrial channels. However, further research and experimental development work, on a laboratory as well as on a pilot-plant scale, will be necessary to solve the many chemical and mechanical problems involved.

Conservatively estimated costs of raw materials for producing molding powders by the methods outlined are indicated in table 3. These costs will vary with the availability and quantity of the raw material required, locality of the manufacturing plant, and with other economic factors. The estimated cost of raw materials for the aniline-hydrolyzed molding composition is somewhat greater than that for the soda-furfural powder and more than twice as great as that of the raw materials used for the acid-hydrolyzed powder. However, the aniline-hydrolyzed powders have certain advantages over those prepared by the other two methods, as discussed previously.

An estimate of the final cost of the finished powder, on a commercial basis, would necessarily include the cost of labor, steam and power, equipment, maintenance and depreciation, taxes, overhead, etc. These items would vary with the type of powder, with the production capacity and location of the plant, and with other economic conditions. Reasonably accurate estimates of these cost items would require pilot-plant rather than laboratory studies.

Comparative investigations on various agricultural residues, including wheat, oat and rye straws, cornstalks, corncobs, flax shives, tobacco stems, bagasse, and lignin residues from the production of furfural, are being conducted at this laboratory. Complete data on the physical properties of molded products from these various materials are not yet available, but preliminary observations indicate that a number of differences exist. However, the black color and outward appearance of the molded product are very much the same for all of these raw materials.

The plastics work of this laboratory will be incorporated into the greatly enlarged program of plastics research to be conducted by the Agricultural Residues Division of the Northern Regional Research Laboratory, United States Department of Agriculture, at Peoria, Illinois. This Division is also actively engaged in investigating the problems of harvesting, collection, transportation, storage and preservation of the agricultural residues -- problems which have a most important bearing on their industrial utilization.

It may be seen from the foregoing studies on bagasse that it appears to be a suitable raw material for the production of low-cost molding compounds. Its ready availability in sizable quantities at the sugar mills is a factor which favors this raw material at the present time. Experimental bagasse molding powders have produced plastic materials with dielectric and other strength characteristics and with resistance to moisture absorption similar to those of phenol-formaldehyde and phenol-furfural molding compounds. The relatively low cost of molding powders produced from bagasse and other agricultural residues should be of considerable interest to the automotive, rubber, electrical, furniture and building industries where large volume production is practiced.

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Table 1. Average annual production for 1931-35, inclusive, and proximate analyses of certain agricultural byproducts (4, 7).

Byproduct	Average production of dry byproduct	Estimated quantity of dry byproduct available for industrial use	Proximate analysis[a]			
			Cellulose	Alpha-Cellulose	Lignin	Pentosans
	1,000 tons	1,000 tons	%	%	%	%
Wheat straw	38,794	29,000	53	34	19	28
Rye straw	2,378	1,800	--	--	--	--
Oat straw	20,156	---	53	44	19	23
Barley straw	5,965	4,474	--	--	--	--
Flax straw	1,128	1,128	65	50	22	20
Rice straw	1,089	820	--	--	--	--
Corn stover	63,681	28,500	46[b]	35[b]	18[b]	28[b]
Corncobs	12,408	1,400	71	43	19	32
Oat hulls	4,651	150	--	--	--	--
Rice hulls	182	182	--	---	--	--
Cottonseed hulls	1,165	583	--	--	--	--
Other hulls	183	92	--	--	--	--
Cotton stems and pods	17,544	12,281	--	--	--	--
Bagasse						
Continental United States	423[c]	423	60	43	19	29
Insular United States	3,276	3,276	--	--	--	--
Total	173,023	84,109	--	--	--	--

[a] Percentages based on oven-dry material.

[b] Analysis of stripped cornstalks.

[c] Estimated 1937-1938 production 786,000 tons (1).

Table 2. Average of certain physical characteristics of plastics produced from sugar cane bagasse.

Treatment of Raw Materials		Yield of Digested Material (basis oven-dry bagasse) %	Flexural Strength (Modulus of Rupture) lb./sq. in.	Izod Impact Strength (Energy Absorbed)		Moisture Absorption (basis oven-dry molded product) %	Specific Gravity	Hardness (Shore Schleroscope)	Bulk* Factor	Moisture in air-dry molded product %
				Notched ft.-lb.	Un-notched ft.-lb.					
Acid-[a] Hydrolysis	Maximum		6983			3.37	1.42	87		1.27
	Minimum		5805			2.29	1.42	83		0.38
	Average	65	6349			2.69	1.42	85		0.80
Aniline-[b] Hydrolysis	Maximum		6900	0.254	0.618	2.99	1.38	90	5.23	0.86
	Minimum		3175	0.074	0.155	0.64	1.28	71	2.50	0.07
	Average	90	4650	0.120	0.254	1.27	1.34	83	3.42	0.270
Soda-Furfural[c] Hydrolysis	Maximum		5982			4.04	1.41	81		1.12
	Minimum		5560			3.57	1.41	81		0.97
	Average	79	5771			3.81	1.41	81		1.04
Commercial Phenol-Formaldehyde	1		7063			0.34	1.34	98		0.25
	2		7107			0.42	1.41	95		0.23
	3		6898			0.38	1.38	95		0.24

* Ratio of volume of finished powder to volume of molded product.

a Digested material plasticized with aniline and furfural.

b Digested material plasticized with furfural, furfural and aniline, or furfural and phenol.

c No plasticizers added.

Table 3. Estimated cost of raw materials for the production of bagasse molding powders. (a) (b)

Raw Materials	Type of Bagasse Powder					
	Acid-Hydrolyzed		Aniline-Hydrolyzed		Soda-Furfural Digested	
	Quantity Required lb.	Cost $	Quantity Required lb.	Cost $	Quantity Required lb.	Cost $
Bagasse, oven dry, at $8.00/ton	2630	10.52	1900	7.60	2165	8.66
Sulfuric Acid, 66°, at $16.50/ton	27	0.22	-	-	910	7.41
Caustic Soda, 76%, at $2.30/cwt.	-	-	-	-	660	15.18
Aniline at $0.15/lb.	135	20.25	535	80.25	135	20.25
Furfural at $0.10/lb.	135	13.50	135	13.50	395	39.50
Zinc Stearate at $0.35/lb.	17	5.95	17	5.95	17	5.95
Total cost per ton of plasticized powder		50.44		107.30		96.50
Cost per lb. of plasticized powder		0.025		0.054		0.04

(a) Based on 1 ton of finished molding powder using average yields as given in table 3.

(b) These figures do not include the costs of labor, steam and power, equipment, maintenance and depreciation, taxes, overhead, etc.

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